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ADP011071

TITLE: Designing Efficient and Effective, Operationally Relevant, High Altitude Training Profiles

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TITLE: Operational Medical Issues in Hypo-and Hyperbaric Conditions
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Designing Efficient and Effective, Operationally Relevant, High Altitude Training Profiles

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Canada experienced a serious case of altitude DCS in Jan 1998 and the author was tasked to review the current high altitude training profiles being conducted by the Canadian Forces (CF) to determine their safety, effectiveness, and to recommend any changes that were deemed necessary. This paper is based on that report (dated 07 July 1999) and focuses on the process that was used to answer these questions.

The initial step was to determine exactly what high altitude training was currently being conducted by Canada and other NATO countries. It became apparent that this training varied widely between countries. An area of concern was the ear and sinus check (a bounce from ground level to 5,000 ft altitude and return to ground level) as some individuals felt the ear and sinus check might be increasing the risk of DCS on the subsequent altitude runs. For the training to be operationally relevant, it had to match the characteristics of the aircraft the students will be flying. Therefore, the characteristics of current aircraft flown in the CF were reviewed.

A few general principles were used to develop the new training profiles and these same principles should be used to refine those profiles as planes and types of flying change. The training must be as realistic as possible. Therefore, the equipment in the altitude chamber should be as similar as possible to the equipment used in the plane the students will be flying (oxygen regulators, face masks, etc.). The rates of ascent and descent in the chamber should match as closely as possible those expected in real situations, while minimizing the risks of DCS/AGE (minimize the time spent above 18,000 ft). The altitudes attained in the chamber should match the altitudes the students will be flying at so that they will have first hand experience with and trust in their life support equipment.

Hypoxia demonstrations must result in signs and symptoms to be effective. If the student does not experience hypoxia, the training has a negative effect (the student thinks they are resistant to hypoxia). Therefore, hypoxia training must be at a high enough altitude for a long enough period of time that virtually all students will experience signs and symptoms. Ground level hypoxia training is not realistic. The students need to relate the experience of hypoxia with altitude. It was also felt that students should experience both the CNS and visual effects of hypoxia. Therefore, hypoxia training was suggested at two altitudes.

Partial pressure breathing is a unique experience for most students. They will experience brief PPB at altitude in the chamber but it was felt that a longer period of time was required for each student to learn how to breath properly against pressure and to communicate while partial pressure breathing. To do this prolonged, individual training at altitude would involve exposures with a very high risk of DCS. Therefore, in addition to the brief altitude PPB experience, ground level PPB training where the student could dial in the PPB according to altitude was felt to be required. The student could be instructed in correct PPB technique and practice communicating on this ground level trainer for as long as was required.

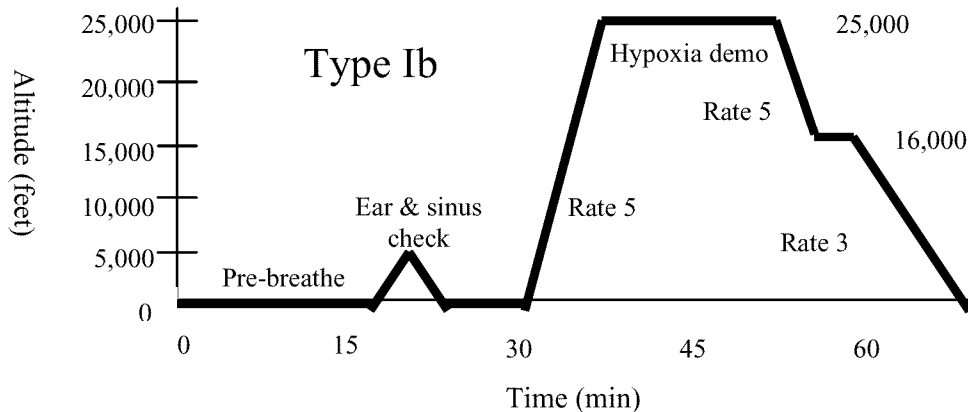
All of these variables were balanced in two new proposed altitude training profiles that could be used for training the crew of all current pressurized aircraft currently used in the Canadian Forces (one profile for aircraft with PPB and one for those without). These profiles could easily be fine tuned for specific aircraft and oxygen regulators. Finally, current altitude training profiles were felt to be irrelevant to the real physiological stresses of aircrew in unpressurized aircraft and helicopters. A profile developed by the Danish Airforce was felt to meet this need and was recommended.

CURRENT CANADIAN FORCES HYPOBARIC PROFILES (1999)

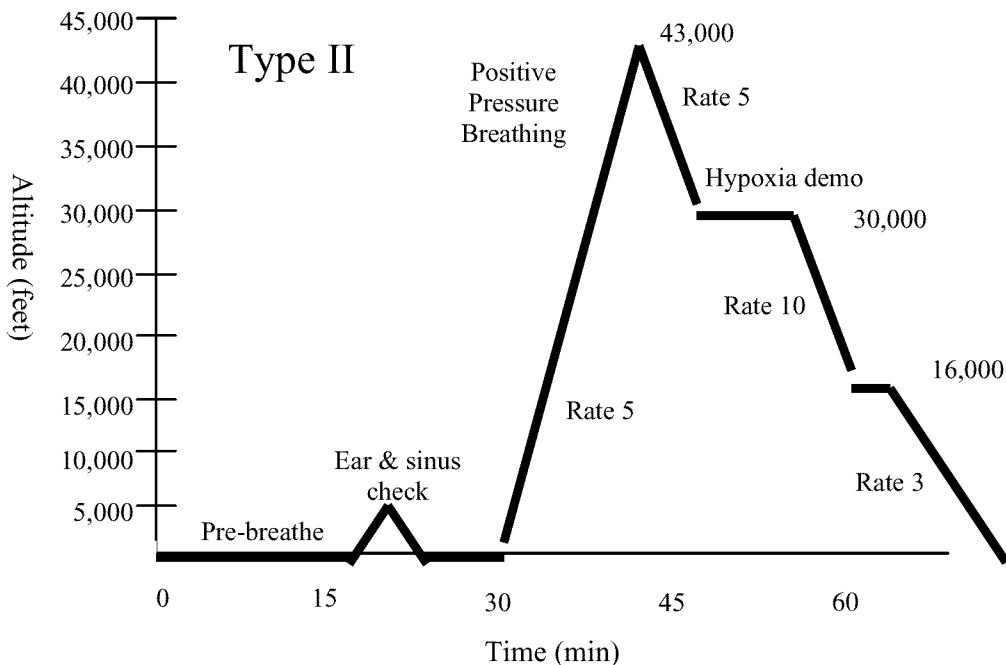
The Canadian Forces aeromedical training currently involves hypobaric chamber exposures as follows:

- Type I Ground to 25,000 ft for hypoxia demonstration and return to ground (three variations)
- Type II Ground to 43,000 ft for positive pressure breathing demonstration, to 30,000 ft for hypoxia demonstration, freefall to 16,000 ft, return to ground
- Type III Rapid decompression from ground to 10,000 ft (one second), return to ground
- Type IV Slow decompression from 4,000 ft to 18,000 ft (10 to 15 seconds), recompression to 9,000 ft and return to ground

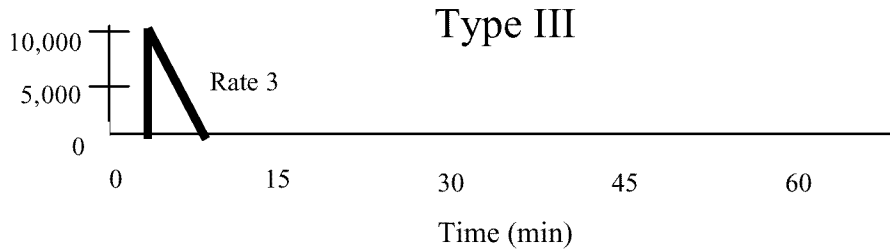
Two additional hypobaric profiles (Types Va and Vb) are conducted as part of HALO (high altitude, low opening parachute jumping) and Sky Hawk (parachute demonstration team) training. These profiles will not be considered in this discussion.



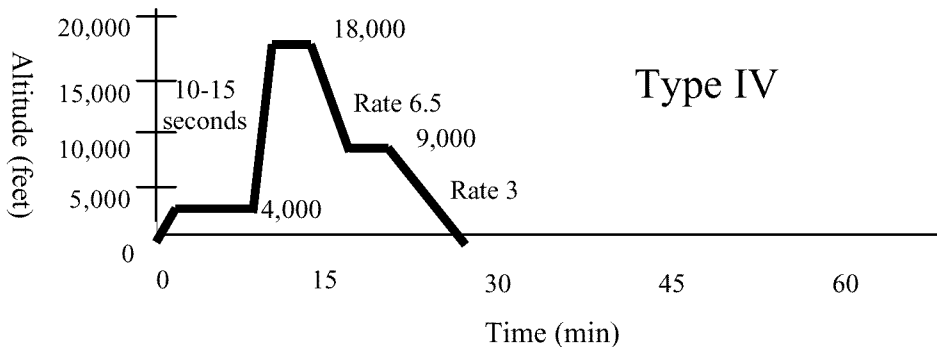
The Type I profile involves hypoxia training at 25,000 ft and has three variations. The most common variation (Type 1b, shown above) is used for all basic aircrew (including pilots and navigators) as well as rotary wing aircrew refresher training. The Type Ia profile differs in that the descent from 25,000 ft to 16,000 ft is at rate 15. It is used for refresher training of ejection seat aircraft crew. Rate refers to the number of feet of altitude change per minute (Rate 15 = 15,000 feet / minute). The Type Ic profile differs in that the descent from 25,000 ft to 9,000 ft is at rate 6.5. It is used for refresher training of non-ejection seat fixed wing aircraft crew. The various descent rates reflect the probable descent rates of the aircrew in an emergency.



The Type II profile involves positive pressure breathing training at 43,000 ft and hypoxia training at 30,000 ft. It is used for all basic pilot training and for pilots flying ejection seat aircraft on refresher training.



The Type III profile involves explosive decompression to 10,000 ft (less than 1 second). The profile is preceded by an ear and sinus check if required. It is used for all basic pilot training and for crew flying ejection seat aircraft on refresher training.



The Type IV profile involves slow decompression (10 to 15 seconds) from 4,000 to 18,000 ft. The profile is preceded by an ear and sinus check if required. It is used for all basic aircrew training, including pilots and navigators.

EAR – SINUS CHECK

Part of the review was to evaluate the requirement for an ear-sinus check (ground to 5,000 ft return to ground) prior to all profiles. It was felt by higher authority that this may be contributing to the development of DCS at higher altitudes and that this was not a common practice in the international aeromedical community. After reviewing the available information, the following observations were made.

The rationale for the ear and sinus check is as follows. Clearing the middle ear on ascent is a passive process as the expanding air in the middle ear forces the eustachian tube open to allow equalization. This process is usually effective even when eustachian tube function is compromised by inflammation due to allergies or infection. Therefore, very few individuals experience difficulty equalizing on ascent.

On descent, the air in the middle ear is compressed, causing a relative vacuum in the middle ear and a further collapse of the normally closed eustachian tube. The person has to actively open the eustachian tube to allow equalization and this process can be extremely difficult or even impossible in the presence of significant inflammation. In addition, if the pressure differential is allowed to become too great, the eustachian tube will “kink” and equalization becomes impossible, even in a normal eustachian tube. Therefore, in an altitude chamber, it is easy to ascend but can be extremely difficult to return to ground level.

The ear and sinus check is to ensure that individuals in the chamber will be able to return to ground level. An altitude of 5,000 ft was chosen so that there would be a great enough volume/pressure change to ensure the person can equalize but not too much to prevent return in case they have difficulty. At 5,000 ft, the atmospheric pressure is approximately 830 mb. Therefore, if the chamber were at sea level, the gas in the

middle ear would expand to $1013/830 = 122\%$ of its original volume. If the person were able to equalize at 5,000 ft but unable to equalize during the return to sea level, the pressure differential that would develop would be at most $(1-100/122) * 14.7 = 2.6$ psi. In reality, the pressure differential would be less as the tympanic membrane, round and oval windows would move in and take up some of the volume. The relative vacuum would result in fluid being drawn into the middle ear until the pressure was equalized and eventually, the person would be able to clear.

If however, the person was taken straight to 25,000 ft and had the same problem, they could be stuck above 18,000 ft, unable to clear, increasing the risk of developing decompression sickness the longer they stayed at altitude. The chamber operators would have no choice but to return them to ground level, rupturing the ear drum in the process. This is unlikely to result in significant harm, but is extremely painful and easily avoided with a simple 5,000 ft ear and sinus check. In addition, in 1977 Nicholas Davenport (4) reviewed 160 cases of barotrauma which occurred during altitude chamber runs. He found that there were no predictors as to which individuals would have problems. Therefore, the ear and sinus check is critically necessary to identify who is able to equalize and who is having problems.

The statement that the ear and sinus check may be contributing to DCI at higher altitudes is suspect. A reduction of 22% in the ambient pressure is equivalent to ascending from a saturation dive at a depth of 7.26 ft. sea water. There is no evidence in the diving literature that a pressure reduction this small contributes to the development of intravascular bubbles or DCS. In fact, the minimum saturation depth from which any bubbles have been seen is 16 ft sea water and the minimum depth which has resulted in any cases of DCS is 26 ft sea water. Therefore, it is extremely difficult to see how the ear and sinus check could be contributing to the later development of DCS. Most NATO countries use the ear and sinus check prior to exposure to higher altitudes.

Therefore, it was concluded that the ear and sinus check is necessary, that it does not significantly contribute to the risk of DCS, and that it should be retained.

CF AIRCRAFT INVENTORY

The current aircraft flown by the CF were reviewed for their cruise altitude, ceiling altitude, and cockpit altitudes, both at cruise and ceiling altitudes. The aircraft were then grouped according to the kinds of physiological stresses the occupants might be exposed to.

The group with the greatest potential physiological stresses are the pressurized aircraft with cabin altitudes above 10,000 ft where the occupants would be exposed to positive pressure breathing if the cabin lost pressurization at the maximum altitude of the plane. The second group are the pressurized aircraft with maximum cabin altitudes of 10,000 ft or less. The third group comprises the fixed wing unpressurized aircraft. The last group is the unpressurized helicopters.

Pressurized, Cabin above 10,000 ft, PPB

| Aircraft | Ceiling Alt. | Cruising Alt. | Cruising – Cabin Altitude |
|--|--------------|---------------|--|
| CF-18 Hornet | 48K | 38-40K | 8K – sea level 23K – 8K 35K – 14.5K 50K – 20K |
| CT-33 Silver Star (2.75 psi differential) | 41K | | 8K – 8K unpressurized 15K – 8K 41K – 25K max (regulations) |
| CT-114 Tutor (3.00 psi differential) | 41K | 25-39K | 8K – 8K unpressurized 17K – 8K 41K – 25K max (regulations) |

Pressurized, Cabin below 10,000 ft

| Aircraft | Ceiling Alt. | Cruising Alt. | Cruising – Cabin Altitude |
|---|--------------|---------------|---|
| CP-140 Aurora | 35K | 31K | 10K max (regulations) |
| CP-140a Arcturus | 35K | 31K | 10K max (regulations) |
| C90A King Air | 30K | 26K | 10K max (regulations) |
| CC-150 Polaris | 41K | 33-39K | 8K max (regulations) |
| CC-144A-Challenger | 41K | 33-37K | 8K max (regulations) |
| CT-142 Dash 8 | 25K | 25K | 8K max (regulations) |
| CC-130 Hercules (15" mercury differential) | 35K | 22-28K | 15K – sea level 20K – 1.5K 25K – 4K 30K – 6K 35K – 8K |

Unpressurized, Fixed Wing

| Aircraft | Ceiling Alt. | Cruising Alt. | Cruising – Cabin Altitude |
|-------------------|--------------|---------------|---------------------------|
| CC-15 Buffalo | 26K | 14-18K | unpressurized |
| CC-138 Twin Otter | 20K | 10K or less | unpressurized |
| T-67C Firefly | 10K | 10K or less | unpressurized |

Unpressurized, Helicopters

| Aircraft | Ceiling Alt. | Cruising Alt. | Cruising – Cabin Altitude |
|-------------------|--------------|---------------|---------------------------|
| CH-113 Labrador | 10K | 10K or less | unpressurized |
| CH-124 Sea King | 10K | 10K or less | unpressurized |
| CH-146 Griffon | 10K | 10K or less | unpressurized |
| CH-139 Jet Ranger | 10K | 10K or less | unpressurized |

PROPOSED NEW HYPOBARIC TRAINING PROFILES

To properly discuss the proposed changes to training hypobaric profiles, it is first necessary to review why altitude exposures are a required part of aeromedical training. The USAF define the purpose of hypobaric chamber flights as, “to demonstrate the hazards associated with changes in barometric pressures and the proper use of protective equipment. These hazards include the symptoms of hypoxia, pressure breathing, mechanical effects of barometric pressure change, and proper use of oxygen equipment”. The training should match as closely as possible the real situations the students are being prepared to meet. This includes the rates of ascent and descent as well as the equipment used in the hypobaric chambers. This practical experience will help the students to become familiar with and trust the safety equipment in the aircraft.

The second step in this process is to examine the types of aircraft the CF currently flies to determine the types of AMT required. The first group of aircraft is comprised of those pressurized aircraft that fly with cabin altitudes above 10,000 ft. Aircrew in these aircraft will be exposed to cabin altitudes up to 25,000 ft (limited by CFP-100, Canadian Forces Flying Orders). If they lose cabin pressure or eject, they will be exposed to positive pressure breathing and very rapid decompression (1-3 seconds) up to maximum altitudes of 48,000 ft. Therefore, these aircrew need to be trained in rapid decompression, positive pressure breathing and hypoxia at both low (visual hypoxia) and higher (CNS hypoxia) altitudes.

The second group of aircraft is comprised of those pressurized aircraft that fly with maximum cabin altitudes of 10,000 ft or less. The aircrew in these aircraft will be exposed to maximum altitudes of 41,000 ft

if they lose cabin pressure but they will not experience positive pressure breathing (or at most minimal PPB) and the rate of decompression should be much slower than in the smaller cockpits. Therefore, they need to be trained in a slower rate of decompression (10-15 seconds) and hypoxia at both higher and lower altitudes.

The third group of aircraft is comprised of those that are unpressurized fixed wing. The aircrew in these aircraft will be exposed to maximum altitudes of 26,000 ft but will normally fly much lower. They will never experience decompression or positive pressure breathing but they do require training in hypoxia.

The last group of aircraft is comprised of the unpressurized helicopters. The references state that these aircraft are limited to a maximum altitude of 10,000 ft but several are capable of flying higher. It is suggested that a lower level hypoxia demonstration (e.g. 10,000 – 15,000 ft) would be useful to these aircrew.

Given the above requirements for altitude chamber training, it is necessary to determine the optimal manner in which this training can be performed, remembering that the training should match as closely as possible the actual situations for which the aircrew are training. A second consideration is the risk of the training. Decompression sickness (DCS) is a risk every time a person is exposed to altitudes above 18,000 ft. Cases of DCS have been reported as low as 12,000 ft but this is extremely rare and these few cases have all been extremely mild. At altitudes above 18,000 ft, the risk of DCS is related to the altitude and the time of exposure. Even then, the cases of DCS are usually very easily treated and do not usually result in any permanent problems, especially when hyperbaric treatment is readily available. One additional caution is to ensure that the students have not been exposed to increased pressure (scuba diving) for at least 48 hours before being exposed to altitude. Diving before ascending to altitude dramatically increases the risk of DCS.

The risk of DCS during AMT can be reduced by having the students pre-breathe for 30 minutes on 100% oxygen (most NATO countries do this) before they ascend to altitude. This procedure removes some of the dissolved nitrogen from the tissues of the body. It does not remove all of the nitrogen and therefore the time spent above 18,000 ft is still a consideration and should be kept to a minimum. Therefore, DCS is a definite risk of altitude training but if hyperbaric treatment is immediately available, permanent problems should be exceedingly rare.

Positive Pressure Breathing. The current training in PPB is fairly realistic in that the PPB is proportional to the altitude but there are several shortfalls. First, the F-18 pilots are not being trained on the regulator that they will be using in the aircraft. Second, the maximum altitude of exposure (43,000 ft) and the maximum PPB are less than could be experienced in a real situation (48,000 ft). Third, the time of exposure to maximum PPB is very short and the students have limited opportunity to learn how to breathe effectively under PPB. Finally, the aircrew will have to communicate while breathing under PPB in the real situation and that is not being effectively trained with the present profiles. Therefore, the following changes are proposed for PPB training.

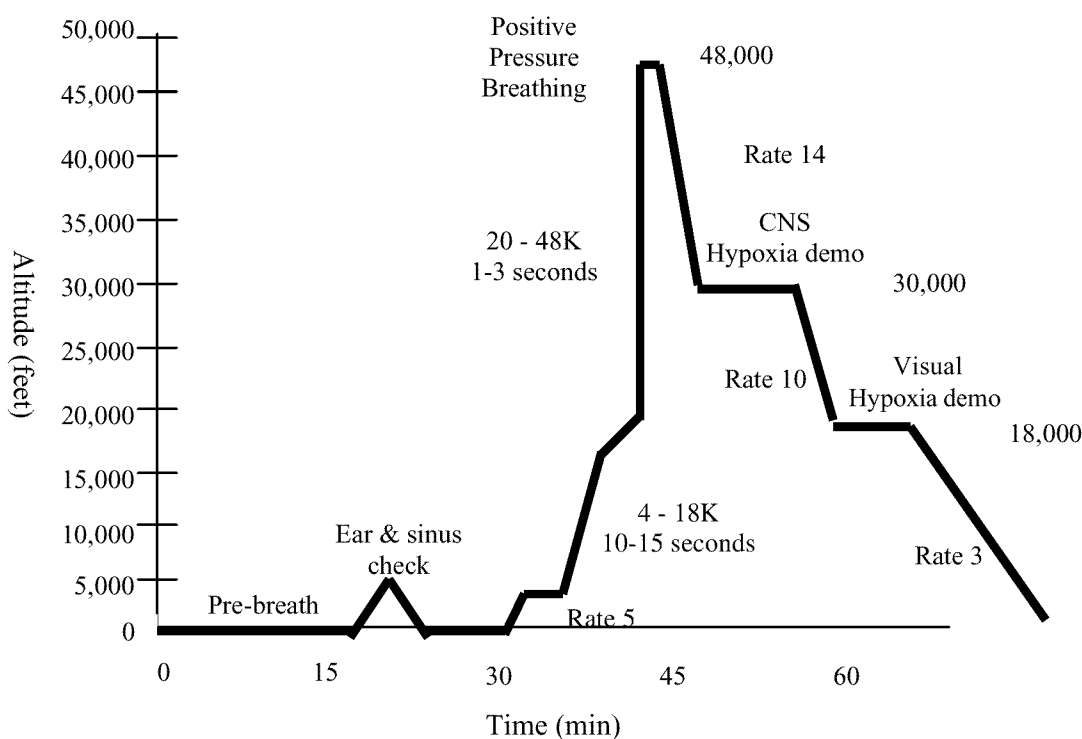
- a. A ground-level PPB trainer needs to be built. The Royal Airforce has designed and built such a trainer (low cost). It has the following features and advantages. The students breathe positive pressure for several minutes and during this training they can match their breathing cycle with the ideal (5 seconds in, 5 seconds out), training themselves to breathe properly under PPB. They also can dial up the altitude to experience the same PPB as they will be exposed to in the aircraft, to a maximum altitude of 48,000 ft. Finally, once the students have learned to breathe properly under maximum PPB, they can practice talking and communicating while under PPB.
- b. The CF altitude chambers at CFSAT and DCIEM need to be equipped with the oxygen regulator used in the F-18. This is considered an operational necessity.
- c. The PPB altitude profile needs to go to 48,000 ft (the operational ceiling of the F-18), and the students need to remain at that altitude for 30 seconds to demonstrate to them that their safety equipment will support them at this altitude. The students will have had extensive ground level PPB training prior to this profile. The increased risk of DCS from going to 48,000 ft instead of the current 43,000 ft is considered small and more than justified by the increased training realism. In addition, other changes to the training profiles should reduce the risk of DCS.

Hypoxia Demonstration. The current training primarily involves hypoxia demonstration at 25,000 ft for a maximum of five minutes off oxygen. Some students also experience a hypoxia demonstration at 30,000 ft for a maximum of 2.5 minutes. The Polish Air Force has demonstrated that many people can go for more

than 10 minutes at a hypoxia level equivalent to 25,000 ft. In addition, it has been the CF experience that many students go the full five minutes at 25,000 ft without experiencing any symptoms of hypoxia, thereby negating the purpose of the training. In addition, current training does not demonstrate the subtle but very real effects of hypoxia at lower altitudes (10,000-20,000 ft, primarily visual). This training would have relevance for many CF aircrew. Therefore, the effectiveness of current CF hypoxia training could be substantially improved. The following changes are proposed for hypoxia training.

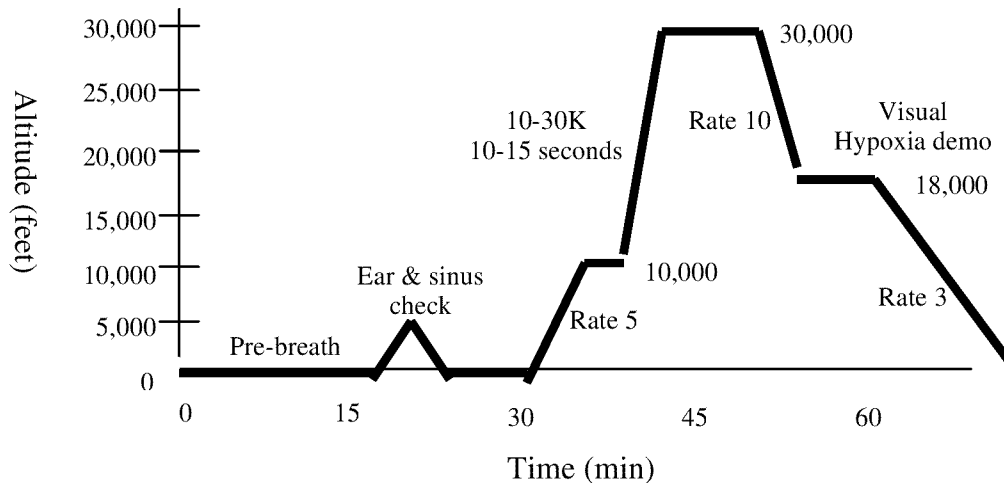
- a. CNS hypoxia training should occur at 30,000 ft with no fixed time limit (currently 25,000 ft for a maximum of 5 minutes for most students). It is anticipated that most students should have definite symptoms of hypoxia in two to three minutes and only rarely will more time be required. In addition, it might be of use to fit each student with an oximeter to demonstrate objectively their level of hypoxia. This change should result in all students experiencing definite symptoms of hypoxia and also reduce the risk of DCS by reducing the time spent above 18,000 ft.
- b. A new hypoxia demonstration should be included in the training at 18,000 ft. This training should be patterned after the USAF training and would primarily demonstrate the effects of this level of hypoxia on vision.
- c. A new low level hypoxia (10,000-13,000 ft) training profile should be created to demonstrate to helicopter and other non-pressurized aircrew the significant visual and psychomotor degradation they can experience at these altitudes. This profile could be patterned after the new Danish profile (their helicopter crews have been extremely pleased with the training).

Rapid and slow decompression training. The current training requires a separate chamber run for each profile. This training could be made much more efficient if it was incorporated into the other profiles. In addition, the current training is unrealistic as the decompressions do not occur at realistic altitudes. Finally, by incorporating the training into the other profiles, the time the students spend above 18,000 ft would be reduced, thereby reducing the risk of DCS.



The above profile is suggested for all aircrew who will be flying in pressurized aircraft that fly with cabin altitudes above 10,000 ft. It should be preceded by ground-level PPB training. The profile starts with a 30 minute pre-breathe on 100% oxygen, during which a 5,000 ft ear and sinus check is done. The chamber can either be decompressed to 20,000 ft (rate 5) or, if the students require it, a decompression from 4,000 ft to 18,000 ft in 10-15 seconds (current Type IV profile) can be conducted during the ascent. They are then

rapidly decompressed (1-3 seconds) from 20,000 ft (maximum cabin altitude in the Hornet) to 48,000 ft (the same pressure change as the current Type III profile and the real altitude change the Hornet pilots would experience). The chamber is then held at 48,000 ft for 30 seconds so that the students can experience maximum PPB and practice communicating. The chamber is then brought to 30,000 ft at the maximum rate of descent of the aircraft/chamber (approximately rate 14) and the CNS hypoxia demonstration is conducted. The chamber is then brought to 18,000 ft at rate 10 and the visual hypoxia demonstration carried out. The time above 18,000 ft should be less than 15 minutes and therefore the risk of DCS should be minimal (current training standards allow 20 minutes and it is often difficult to complete the training in this time).



The above profile is suggested for all other aircrew. It starts with a 30 minute pre-breathe on 100% oxygen, during which a 5,000 ft ear and sinus check is done. The chamber is brought to 10,000 ft and the students remove their masks (they would not be wearing them in the plane). Breathing air at 10,000 ft does not interfere with the oxygen pre-breathe as the students will still be off-gassing nitrogen breathing air at this altitude. The students are exposed to slow decompression from 10,000 ft to 30,000 ft in 10-15 seconds (replaces current Type IV profile and simulates the real decompression likely to be experienced in a large pressurized aircraft). The students can either go straight into the CNS hypoxia demonstration at 30,000 ft or they can all don their oxygen masks and do their safety drills before starting the hypoxia demonstration. Alternatively, ½ the students could don their oxygen masks while the remainder go straight in to the hypoxia demonstration. The rest of the profile is identical to the previous profile and the time above 18,000 ft should be less than 10 minutes.

It is also suggested that the helicopter, and possibly non-pressurized transport (plus CC130) crews be given the 13,000 ft training profile developed by the Danish Air Force (see ref 1).

Finally, as new aircraft are brought into service in the CF, the above training parameters need to be adjusted to reflect the flight characteristics of the new aircraft. In addition, if the new aircraft use a different oxygen regulator, it needs to be installed in the altitude chambers at CFSAT and DCIEM to ensure the continued usefulness of the training.

Subsequent to this report, a review committee determined that the maximum PPB with the oxygen regulator used in the F-18 is attained by 43,000 ft. Therefore, it was decided to limit the first training profile to a maximum altitude of 43,000 ft and to not go to 48,000 ft.

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